AEROSPACE MATERIAL SPECIFICATION

AMS2694™	REV. D

Issued 1980-04
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Revised 2024-06

Superseding AMS2694C

In-Process Welding of Castings

RATIONALE

AMS2694D results from a Five-Year Review and update of this specification, moving Ordering Information to the beginning, moving definitions to 2.7, replacing “purchase order, drawing, and specification” with “specified” throughout, replacing “purchaser” with “CEO” as applicable throughout, and replacing “defects” with “discontinuities” throughout.

NOTICE

ORDERING INFORMATION: The following information shall be provided to the welding processor by the purchaser:

Purchase order shall specify not less than the following:

- AMS2694D
- Filler metal to be used, if other than nominal composition (see 3.4.2)
- Limits on location, size, depth, number, and spacing of welds, if any (see 3.2)
- Post-weld heat treatment (thermal treatments required after welding), if other than 3.5.8
- Weld maps (or equivalent), when required (see 3.6.4)
- Inspection methods and frequency of examination, if different from the base material requirements (see 3.6)
- Finishing requirements, if other than specified in this specification (see 3.5.2.2.2)
- In addition, ordering documents need to state, as applicable:
  a. If welding procedure specification (WPS) and/or procedure qualification record (PQR) of AWS D17.1, ASTM A488/A488M, or other specified standard are required
  b. If welder qualifications are contingent upon satisfying mechanical property requirements specified in the material specification, and/or
  c. If the processor’s procedures are subject to cognizant engineering organization (CEO) review and approval

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: **http://www.sae.org**

For more information on this standard, visit
https://www.sae.org/standards/content/AMS2694D

Parts manufacturing operations such as heat treating, forming, and media finishing can affect the condition of the substrate for welding or, if performed after welding, could adversely affect the welded part. The sequencing of these types of operations should be specified by the cognizant engineering organization or purchaser and is not controlled by this specification.

1. SCOPE

1.1 Purpose

This specification defines the requirements for in-process correction of foundry discontinuities by manual welding of castings.

1.2 Application

This specification provides a means for cognizant engineering organizations (CEO) to specify in-process manual welding procedures and manual welder qualification methods for correction of foundry discontinuities in castings. This specification does not apply to correction of casting discontinuities detected during machining or subsequent operations, modification of a sound casting for engineering purposes (see 3.3.3.a), or fabrication performed on or with castings.

1.3 Safety - Hazardous Materials

While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards which may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The processor may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS2175 Castings, Classification and Inspection of

AS7766 Terms Used in Aerospace Metals Specification

2.2 U.S. Government Publications

Copies of these documents are available online at https://quicksearch.dla.mil.

A-A-59503 Nitrogen, Technical

BB-C-101 Carbon Dioxide (CO_2): Technical and USP

BB-H-886 Hydrogen

BB-H-1168 Helium, Technical

MIL-A-18455 Argon, Technical

2.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM A488/A488M Steel Castings, Welding, Qualifications of Procedures and Personnel

ASTM E1417 Liquid Penetrant Testing

ASTM E1444 Magnetic Particle Testing for Aerospace

ASTM E1742 Radiographic Examination

2.4 AWS Publications

Available from American Welding Society, 8669 NW 36 Street, #130, Miami, FL 33166-6672, Tel: 1-800-443-9353 or 305-443-9353, www.aws.org.

AWS A5.12/A5.12M Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting

AWS D17.1/D17.1M Specification for Fusion Welding for Aerospace Applications

AWS QC1 Specification for AWS Certification of Welding Inspectors

2.5 CGA Publications (Compressed Gas Association)

Available from CGA, 14501 George Carter Way, Suite 103, Chantilly, VA 20151, Tel: 703-788-2700, www.cganet.com.

CGA-4.3 Commodity Specification for Oxygen

CGA-5.3 Commodity Specification for Hydrogen

CGA-6.2 Commodity Specification for Carbon Dioxide

CGA-9.1 Commodity Specification for Helium

CGA-10.1 Commodity Specification for Nitrogen

CGA-11.1 Commodity Specification for Argon

2.6 ISO Publications

Available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, www.iso.org.

ISO 24394 Welding for aerospace applications- Qualification test for welders and welding operators - Fusion welding of metallic components.

2.7 Definitions

Terms used in AMS2694 are defined in AS7766, AWS D17.1, and as follows:

2.7.1 SPECIFIED

Requires documented instruction from the CEO through engineering drawing, purchase order, specification, or other engineering documentation.

2.7.2 NOMINAL COMPOSITION

Includes equivalent, if not identical, controls and limits on composition. An example is, but not limited to, iron levels in 357 aluminum alloys.

2.7.3 AUTOGENOUS WELD

A fusion weld made without filler metal.

3. TECHNICAL REQUIREMENTS

3.1 When performed, castings shall be welded in any as-cast or heat-treated condition appropriate to the alloy that will allow the welded casting to meet the material specification and other specified requirements (see 3.5.8 and Ordering Information). All welding shall be manual welding.

3.2 Welding shall be performed only in those areas and to the extent specified, or as otherwise agreed upon by the CEO and processor.

3.3 Correction by Welding

3.3.1 Casting nonconformances may be corrected by welding.

3.3.1.1 Examples of nonconformances allowed to be corrected by welding include cracks, handling damage, miscuts, laps, hot tears, cold shuts, cold shots, shrinkage, porosity, gas holes, inclusions, oxides, dross, and other nonmetallic material.

3.3.2 Mis-machined target points may be corrected by adding weld filler to the target point surface(s) and (re)machining (see 3.3.3.d).

3.3.3 Unless authorized by the CEO, welding shall not be used to:

a. Correct dimensional discrepancies that are a product of the pattern or core tooling, or to modify a sound casting for engineering purposes except as noted in 3.3.1.

b. Correct casting discontinuities detected during machining or subsequent operations.

c. Fabricate or assemble castings or portions of castings.

d. Weld on target points after final heat treatment and dimensional inspection.

e. Weld broken features back onto the casting.

3.3.4 When authorized by the CEO, patches, sections, or plates of cast and wrought materials may be used to correct the conditions described in 3.3.1.

3.4 Materials and Equipment

3.4.1 Gases for welding, shielding, backing, and chambers shall be in conformance with Table 1.

Table 1 - Shielding gasses

Gas	Specification	Alternate Specification
Argon	CGA G-11.1, QVL C or better	MIL-A-18455
Helium	CGA G-9.1, QVL L or better	BB-H-1168
Oxygen	CGA G-4.3, QVL C or better	BB-0-925, Type I or II
Nitrogen	CGA G-10.1, QVL L or better	A-A-59503, Type I or II, Class 1, Grade B
Hydrogen	CGA G-5.3, QVL B or better	BB-H-886, Type I or II
Carbon Dioxide	CGA G-6.2, QVL G or better	BB-C-101, Grade B
Gas Mixtures	Gas purity shall conform to the type and/or grade specified above. The composition shall be in accordance with the welding procedure, or as specified by the CEO.	Gas purity shall conform to the type and/or grade specified above. The composition shall be in accordance with the welding procedure, or as specified by the CEO.

3.4.2 Unless otherwise specified or authorized by the CEO, welding filler metal type shall be the same nominal composition (see 2.7.2) as the casting composition and, when specified, shall be procured to the applicable filler metal specification (see 8.2).

3.4.2.1 Filler metal type shall be identified and traceable to the applicable filler metal specification. If the identification and traceability is lost, the filler metal shall not be used. Traceability shall be maintained in accordance with 3.5.7.3.

3.4.2.2 Filler metal shall be stored in a clean and dry environment. Heating of the storage cabinet used for coated electrodes may be employed as necessary to prevent moisture accumulation. Filler metal types shall not be mixed during storage or use.

3.4.3 Equipment shall be maintained as required to facilitate meeting specified requirements.

3.4.4 Tungsten electrodes shall be in accordance with AWS A5.12/A5.12M.

3.5 Welding Procedure

3.5.1 Welding shall be accomplished in accordance with written work instructions. These instructions shall include, but are not limited to, welding process, alloy type and pre-weld heat-treatment condition, pre-weld conditioning, welding filler metal, preheat and/or post-heat temperature as applicable, control of rewelding, and subsequent processing including post-weld thermal treatment. Supplemental instructions for each CEO or casting part number shall be established as required to control the CEO or casting specific items such as cleaning, inspection, weld zone locations and allowances, thermal treatments, and special qualification procedures.

3.5.2 Preparation, Welding and Finishing

3.5.2.1 Casting nonconformances to be corrected shall be prepared in accordance with 3.5.2.2 by a method that does not damage the base metal. The prepared area shall be smoothly contoured prior to welding.

3.5.2.1.1 For autogenous welding of 3.5.2.2.1, it is not necessary to remove the discontinuities.

3.5.2.2 The area shall be examined prior to welding to ensure that the nonconformance has been removed or reduced to the extent required. The method(s) of in-process examination shall be any suitable combination of visual and/or nondestructive inspections used to determine final acceptance of the weld. Cracks, laps, hot tears, cold shuts, cold shots, and other linear discontinuities shall be removed completely, unless otherwise authorized by the CEO. Other discontinuities such as shrinkage, porosity, gas holes, inclusions, dross, and other nonmetallic material shall be removed to the extent necessary to produce a sound weld acceptable to 3.6 (see 8.6).

3.5.2.2.1 When authorized by the CEO, surface-contained gas holes, pits, HIP sinks, porosity, cold shuts, and cold shots may be reworked using autogenous welding. Filler material may be added for dimensional compliance.

3.5.2.2.2 The weld area, heat-affected zone, weld filler metal, and fixturing if required shall be free from slag, surface oxides, scale, oils, grease, dirt, and other contaminants. Chemical methods or mechanical methods shall be used, as appropriate, to remove contamination before welding. Chlorinated solvents or methyl alcohol shall not be used to clean titanium or titanium alloys. Stainless steel wire brushes or carbon steel wire brushes may be used on carbon or low alloy steels. Only stainless steel wire brushes shall be used on all other materials being welded. Once an individual wire brush is used on a certain material group (i.e., titanium, aluminum, nickel-base alloys, etc.), it shall be suitably identified and used only on that material group.

3.5.3 Castings may be preheated or pre-weld stress-relieved in accordance with the weld procedure as required to provide good weld quality.

3.5.4 Welding shall be accomplished by manual gas-tungsten-arc welding (GTAW), unless use of another manual process such as plasma arc welding (PAW), gas metal arc welding (GMAW), or shielded metal arc welding (SMAW) is authorized by the CEO.

3.5.4.1 The weld and heat affected zone shall be protected from oxidation during welding using a shielding gas (see 3.4.1). When welding titanium and titanium alloys, backup shielding gas shall be used, and metal deposited behind the weld pool shall be shielded.

3.5.5 Welding shall be performed by welders qualified in accordance with 3.8.

3.5.6 Welded areas shall be blended to conform to specified requirements. Root weld reinforcement, penetration, and drop-through in inaccessible areas shall be blended in accordance with the CEO's requirements. Unless otherwise specified by the CEO, the perimeter of the weld shall be blended flush with the parent metal (see 8.4 and 8.5).

3.5.7 Identification

3.5.7.1 Welded areas shall remain traceable to their location on the castings until inspection is completed (see 3.6).

3.5.7.2 When specified, welded castings shall be marked with a symbol of the type, method, and in the place specified by the CEO.

3.5.7.3 Traceability of welder personnel and lot number of filler material shall be maintained by the processor through shop traveler, weld map, or other record suitable to satisfy specified requirements, and as necessary to demonstrate continuing welder proficiency or qualification status.

3.5.8 Heat Treatment

After all welding is complete, castings shall be heat treated as specified.

3.5.8.1 When austenitizing, annealing, normalizing, or solution treating are not specified, post-weld stress-relief heat treatment shall be performed, as appropriate to the alloy, unless otherwise specified by the CEO.

3.5.8.2 Post-weld stress-relief is allowed prior to required heat treatment, as appropriate to the alloy.

3.6 Inspection of Welded Castings

3.6.1 Welded areas shall be inspected after completion of all blending, using the same inspection procedures and acceptance standards required of the casting. The inspection of the welded areas may be performed at the same time as final visual, fluorescent penetrant, and/or magnetic particle, and radiographic acceptance inspection of the casting to the specified requirements, if conducted after all required heat treatments including any stress relief. Final radiographic inspection may be performed before the required heat treatment when authorized by the CEO but shall be performed after completion of all welding and blending. Linear indications are not permitted unless authorized by the CEO.

3.6.2 Personnel performing in-process and final visual inspections shall be trained and qualified in accordance with the processor's documented procedure. Approval of the procedure by the CEO is not required. Welders may perform in-process visual inspection. Certification of visual weld inspectors to AWS QC1 is not required.

3.6.3 If inspection methods are not specified, then one or more of the following methods acceptable to the CEO shall be used as applicable: fluorescent penetrant inspection in accordance with ASTM E1417, magnetic particle inspection in accordance with ASTM E1444, and/or radiographic inspection in accordance with ASTM E1742.

3.6.4 When specified, radiographic images or weld maps shall be identified with the welded region for each casting welded and shipped with the castings or retained in accordance with specified requirements (see 4.6.1).

3.7 Control of Rewelding

3.7.1 In-process correction of weld-related nonconformances is permitted prior to post-weld heat treatment. Each nonconformance shall be prepared, welded, blended, and inspected in accordance with the work instructions (see 3.5 and 3.6).

3.7.2 Any welded area which contains nonconformances after post-weld heat treatment and inspection shall be re-prepared, rewelded, reblended, and reinspected in accordance with the work instructions and all requirements of 3.5 and 3.6, including post-weld thermal treatment in accordance with 3.5.8. Additional process limitations, if required, shall be as specified by the CEO.

3.8 Welder Qualification

3.8.1 Welders shall meet the physical requirements of AWS D17.1. When color recognition is required (for example, for color coded or flagged wire, or for evaluation of titanium for oxygen contamination), then the ability to discern the differences between the required colors shall be demonstrated and documented in the welder qualification record.

3.8.2 Welders shall be qualified by welding cast specimens to the requirements of this AMS and the essential variables of 3.8.5. Cast specimen weld areas shall be prepared by machining or shall be cast net and prepared in accordance with 3.5.2. Specimen configuration shall be as shown in Figure 1, or as shown in the TP6 test piece of ISO 24394, or another configuration representative of the casting features to be welded.

3.8.2.1 Alternatively, qualification by the groove weld performance and procedure qualification requirements of AWS D17.1 or ASTM A488 is permitted, except that ASTM A488 qualification must be achieved for each welding process (GTAW, SMAW, PAW, or GMAW).

3.8.2.2 Alternatively, qualification for the repair of castings to ISO 24394 is permitted, including any “X” designation special qualification test appropriate to the welding of castings.

3.8.3 Alternatives to 3.8.2

When specified, the processor’s welder(s) shall be qualified by welding and subsequent mechanical testing of welds in plates (such as those in Figure 1 or equivalent) to procedures and standards agreed upon between the CEO and processor. The processor may use an alternative qualification procedure when authorized by the CEO.

3.8.4 At least one test weld shall be required for each combination of welding conditions. Test welds shall be accomplished in accordance with a written weld test procedure governing each of the material groups of Table 2 for which qualification is attempted. The weld test procedure shall include the essential variables used to accomplish base metal group qualification of Table 2. Unless otherwise specified, qualification is not required for the weld test procedure.

Table 2 - Samples of Alloys Contained in Material Groups

Base Metal Group[1]	Alloy Type	Typical Cast Alloys[1][5]
Group IA	Carbon and Alloy Steels[2]	8615 17Ni - 10Co Maraging, 18.5Ni - 9Co Maraging
Group IB	Heat-Treatable Alloy Steels[2]	4130, 4140, 8630
Group IIA	Stainless Steels and Other Iron Base Alloys[2]	304L, 310/CK-20, 316, 347, 410, 416 Free Machining[3], 431, 440C (4), Greek Ascoloy®, N155
Group IIB	Precipitation Hardening Steels[2]	14-4PH®, 15-5PH®, 17-4PH®, AM 355®, PH 13-8 Mo®
Group IIIA	Nickel Base Alloys[2]	Hastelloy® B, Hastelloy® C, Hastelloy® X, Inconel® 625
Group IIIB	Precipitation Hardening Nickel Base Alloys[2]	505, IN®713C and LC, Inconel® 718, IN® 738, IN® 792, Rene® 41, Udimet® 500, Waspaloy®
Group IVA	Non-Heat-Treatable Aluminum Alloys[2]	--
Group IVB	Heat-Treatable Aluminum Alloys[2]	201, 203, 206, 243, 355, 356, 357, 360, 380
Group V	Cast Magnesium Alloys	AM100A, AZ63A, AZ91, AZ92, EQ21, EZ33A, QE22A, WE43A, WE54, ZE41A, ZE63, ZK51A, ZK61A
Group VI	Titanium Base Alloys	6Al-4V, 6Al-2Mo-4Zr-2Sn
Group VII	Cobalt Base Alloys	S-6, S-21, S-30, S-31, FSX-414, F75, Haynes® 188, WI-52
Group VIII	Copper Base Alloys Zinc Base Alloys	Aluminum Bronze, Leaded Red Brass[3], Leaded Bronze[3], Manganese Bronze, Nickel Aluminum Bronze, Tin Bronze, AG40A[4]

(1) Alloys listed are covered by one or more current AMS casting specifications. The grouping of alloys is similar to that of AWS D17.1. Except as marked in Group VIII, alloys not listed may be assigned in accordance with examples in D17.1 or by the CEO. The processor may assign alloys if acceptable to the CEO.
(2) Welders qualified for Group B (e.g., Group 1B) may weld Group A (e.g., Group 1A) without additional qualification.
(3) Qualification for this alloy must be performed on samples of it and does not qualify for other alloys except other free machining types within the group.
(4) Qualification for this alloy must be performed on samples of it and does not qualify for other alloys within the group.
(5) The designations are trademarks or commercial designations and are for alloy recognition only.

3.8.5 Each individual qualification shall be separate and distinct from any other based upon the following variables:

3.8.5.1 Welding process - GTAW, SMAW, PAW, or GMAW. For GTAW, AC and DC polarity to be qualified separately. For GMAW, changes in transfer modes to be qualified separately.

3.8.5.2 Base metal grouping of Table 2.

3.8.5.3 Backing

Test piece welded with backing or heat sinks qualifies only for in-process welding with backing or heat sinks. Test piece welded without backing or heat sinks qualifies for in-process welding with or without backing or heat sinks.

3.8.5.4 Position

The test piece shall be welded in the same position(s) as the castings to be welded. A single test piece may be rotated during qualification to simulate all of the necessary positions (i.e., flat, horizontal, vertical).

3.8.5.5 Thickness

A test weld thickness (depth) of 1t shall qualify welds with a thickness range of 0.67t to 4t, except when the test weld thickness is equal to or greater than 1 inch (25 mm) the qualification range is 0.67t to unlimited. Two test welds shall qualify welds with all intermediate thicknesses.

3.8.6 When specified, welding procedure specification (WPS) and procedure qualification record (PQR) shall be established using specified requirements, e.g., the criteria of ASTM A488.

3.8.7 Test welds shall be inspected by radiographic and fluorescent penetrant examination to the Grade A acceptance criteria of AMS2175. Inspection may be performed to Grades B or C, as applicable, if the welder's qualification is restricted to welds in those Grade areas of castings. Test welds shall be sectioned and evaluated metallographically for complete fusion and freedom from linear discontinuities. Unless otherwise specified, mechanical testing of test welds is not required.

3.8.8 In event of failure, the weld test shall be repeated.

3.8.9 Welder qualification shall not transfer between processors or between sites of multisite processors unless all process variables of 3.8.5 are the same.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The casting producer shall supply all samples for the processor's tests and shall be responsible for performance of all required tests. The CEO reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the castings conform to the requirements of this specification.

4.2 Classification of Tests

4.2.1 Acceptance Tests

Tests to determine conformance to the inspection requirements (see 3.6) for welded castings are acceptance tests.

4.2.2 Periodic Tests

Welder qualification requirements of 3.8 are periodic tests and shall be performed at the frequency required by AWS D17.1, unless otherwise specified. Alternatively, a system acceptable to the CEO documenting continuing welder proficiency may be used.

4.2.3 Preproduction Tests

4.2.3.1 Welder qualification requirements of 3.8 are preproduction tests and shall be performed prior to in-process welding of production castings.

4.2.3.2 Preproduction welding and testing of each casting part number is not required unless specified. When required by the CEO, an evaluation of the welding procedure shall be performed using the specified criteria.

4.3 Sampling shall not be less than the following:

4.3.1 Acceptance Tests

Welded castings shall be inspected in accordance with 3.6 and specified requirements.

4.3.2 Periodic and Preproduction Tests

Samples shall be tested in accordance with 3.8, except periodic requalification testing is not required when proficiency testing is allowed.

4.4 Approval

4.4.1 When specified, the processor's welder qualification procedure and/or the processor's procedure for welding of products shall be approved by the CEO.

4.5 Reports

Unless otherwise specified, certifications for shipments containing welded castings shall contain the following notation (or equivalent): "In-process welding has been performed in accordance with AMS2694D. In-process records and inspection results are on file at this facility and are available to purchaser upon request."

4.6 Records

Records of welding procedures and welder qualifications and requalifications, including welder proficiency when applicable, shall be maintained on file by the processor in accordance with the CEO's retention requirements.

4.6.1 Certificates of conformance, inspection results, radiographic images, and weld maps, if required, shall be maintained on file at the processor, or submitted to the CEO, in accordance with specified requirements.

4.6.2 Welder qualification results shall document the welder, date of test, welding process, alloy, condition, position, backing, thickness, casting tested if applicable, test results, and alloy group for which the welder qualifies based on this test, and if corrected vision is required (see 3.8.1).

4.7 Resampling and Retesting

4.7.1 If results of any acceptance inspection of welded castings fail to meet specified requirements, the castings may be rewelded in accordance with 3.7.

4.7.2 If results of any periodic qualification test fail to meet specified test requirements, the welder shall be disqualified except as specified in 4.7.2.1. If failure to maintain continuing proficiency standards required by the processor and acceptable to the CEO occurs, the welder shall be disqualified. If there is a specific reason to question the ability of the welder to meet the requirements for qualification, the welder shall be disqualified. No additional production castings may be welded by a disqualified welder until new qualification requirements are satisfied.

4.7.2.1 The welder shall not be disqualified if mechanical property or other requirements are not met when failure occurs in parent metal outside of the weld or heat affected zone, or if metallurgical investigation establishes that nonconforming mechanical test results are not a result of the welder's technique.

5. PREPARATION FOR DELIVERY

Not applicable.

6. ACKNOWLEDGMENT

Not applicable.

7. REJECTIONS

Welded castings that do not conform to the requirements of this specification or modifications authorized by the CEO shall be subject to rejection.

8. NOTES

8.1 Revision Indicator

A change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.